

**SCALE UP STUDY ON PRODUCTION OF BIODIESEL FROM JATROPHA
CRUDE OIL**

AINUL NADIRAH BINTI IZAHARUDDIN

Faculty of Chemical and Natural Resources Engineering
Universiti Malaysia Pahang

ABSTRACT

Scale up is a very important activity in designing new industrial plants especially in specialty or fine chemicals production. In this work, bench scale and pilot plant scale up factors are examined in producing biodiesel from *Jatropha* oil. The production of biodiesel in bench scale is compared to the pilot plant scale production. There are two processes involved in this work i.e. esterification process and transesterification process. The esterification process used H_2SO_4 as a catalyst while in transesterification process used NaOH as a catalyst. The ratio between *Jatropha* oil to methanol, the time reaction, and the temperature are similar in both scales. From the result, it was found that for bench scale and pilot plant scale, there are some differences in the value of the final yield. The difference value between the bench scale and pilot plant run was caused by several factors such as handling, operating conditions etc.

ABSTRAK

Peningkatan skala merupakan kegiatan yang sangat penting dalam perancangan kilang industri baru terutama pengeluaran bahan kimia yang khusus atau yang kecil. Dalam kajian ini, skala makmal dan skala pilot plant peningkatan skala dikaji dalam menghasilkan biodiesel dari minyak buah jarak. Pengeluaran biodiesel dalam skala makmal dibandingkan dengan pengeluaran skala pilot plant. Dua proses yang terlibat dalam eksperimen ini iaitu proses pengesteran dan pengtransesteran. Proses pengesteran digunakan H_2SO_4 sebagai pemangkin sementara dalam proses pengtransesteran menggunakan NaOH sebagai pemangkin. Nisbah antara minyak buah jarak dengan Metanol, masa, dan suhu adalah sama pada kedua-dua skala. Dari hasil tersebut, didapati bahawa untuk skala makmal dan skala pilot plant, ada beberapa perbezaan dalam nilai akhir pengeluaran. Perbezaan antara skala makmal dan skala pilot plant disebabkan oleh beberapa faktor seperti pengendalian, keadaan operasi dll

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
R		
	TITLE PAGE	i
	DECLARATION	ii
	DEDICATION	iv
	ACKNOWLEDGEMENT	v
	ABSTRACT	vi
	ABSTRAK	vii
	TABLE OF CONTENT	viii
	LIST OF TABLE	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS	xiii
1	INTRODUCTION	1
	1.1 Introduction on scale up production	1-2
	1.2 Introduction on biodiesel	2-6
	1.2.1 Composition of Biodiesel	6-7
	1.2.2 Mechanism of Esterification and Transesterification	7-8
	1.3 Objective of Study	8

2	LITERATURE REVIEW	9
2.1	Scale up on chemical processes	9
2.1.1	Scale up	9-11
2.1.2	Raw material	11-12
2.1.3	Utilities	12
2.2	Biodiesel Process	13
2.2.1	Catalytic Transesterification	13-14
2.2.2	Background of catalyst in biodiesel production	14
2.2.2.1	Base catalyst.	14-15
2.2.2.2	Acid catalysis	15
2.2.2.3	Esterification of FFAs	15-16
2.2.2.4	Transesterification of Triglycerides	16-17
2.3	<i>Jatropha curcas</i> L. seed oil for biodiesel production.	17-20
2.3.1	The multi-uses of <i>Jatropha curcas</i> Plant	20-21
3	METHODOLOGY	22
3.0	Introduction	23
3.1	Experimental methodology	23-24
3.1.1	Lab Scale	24-25
3.1.2	Pilot plant scale	25-26
3.2	Product analysis	26
3.2.1	Gas chromatography (GC/FID)	26-27
3.2.2	Yield calculation	27

4	RESULT AND DISCUSSION	28
4.1	Introduction	28
4.2	GC/FID Analysis	28
4.2.1	Methyl Stearate analysis	28-29
4.2.2	Methyl Palmitate analysis	30-31
4.3	Yield analysis	31-32
5	CONCLUSIONS & RECOMMENDATIONS	33
5.0	Introduction	33
5.1	Conclusions	33
5.2	Recommendations	34
	REFERENCES	35-36

LIST OF TABLE

TABLE	TITLE	PAGE
1.1	Chemical properties of vegetable oil on the basis of their fatty acid composition, % by weight (Ma 1999).	6
1.2	Typical fatty acid composition-common oil source (Ma, 1999)	6
1.3	Chemical structures of common fatty acid and their methyl esters.	7
2.1	Fatty acid composition of crudes <i>Jatropha curcas</i> (H.J Berchmans et al. 2007)	18
2.2	The problems in use of Jatropha Oil as fuel in Diesel Engine	20
2.3	Fuel Properties of Jatropha Oil and its biodiesel	24
4.1a	Value of concentration and Area of Methyl Stearate	29
4.1b	Value of Area and Time Retention for every sample	29
4.2a	Value of Concentration and Area of Methyl Palmitate	30
4.2b	Value of Area and Retention time for every sample	30
4.3	Yield value of the production	32

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Mechanism of acid catalyzed transesterification of vegetable oil.	4
1.2	Mechanism of base – catalyzed transesterification of vegetable oils	5
2.1	Essential steps in process development for scale up	11
2.2	Schematic of transesterification process	14
2.3	<i>Jatropha curcas</i> L. seed oil plant on rocky substrate	19
3.1	Flow chart methodology of biodiesel production in scaling up	23
3.2	The overall process of the production biodiesel	24
3.3	Gas Chromatography (GC/FID)	27
4.1	Area (%) vs Concentration (g/mL) graph	29
4.2	Area (%) vs Concentration (g/mL) graph.	31
4.3	Lab scale yield (%) vs Pilot plant scale yield (%) graph	32

LIST OF SYMBOLS

g	-	Gram
h	-	Hour
ρ	-	Density
$^{\circ}\text{C}$	-	Degree Celsius
kg	-	Kilogram
C	-	Concentration
L	-	Liter
mm	-	Mililiter
μm	-	Mikrometer
mL	-	Mililiter
min	-	Minute
V	-	Volume
mg	-	Miligram

CHAPTER I

INTRODUCTION

1.4 Introduction on scale up production

The starting point generally consists of laboratory results that concern a chemical transformation whose translation into economic gain appears viable. Process development should serve to treat quantities of raw materials industrially, amounting to tons or millions of tons, whereas only grams or kilograms of these raw materials are used in the laboratory. This is the precise function of change of scale or scale up. The problem is to reproduce the laboratory results on a large scale: in other words, to achieve the same conversions, yields and selectivity, and, in some cases, possibly improve the results.

To go directly from the laboratory to the industrial scale is rarely feasible. As a rule, one or more additional experiments are necessary. Specifically, the problem is to define these additional steps in order to gather all the information required at minimum cost and as quickly as possible. It is here that the methodology of process development, and hence of scale up, becomes decisive for the success of the operation.

In laboratory-type experiments, certain aspects of the process are investigated, by handling relatively small amounts of raw materials in order to reduce the material constraints to the minimum. In Pilot-plant experiments, at a scale that varies within wide

proportions, but in which all the industrial constraints are taken into account: impurities in raw materials, operation over long periods, materials, equipment reliability, etc. It is during pilot-plant experiments that scale up problems must be dealt with. The pilot-plant experiments alone cannot yield all the answers needed to solve the problem of scale up, and that additional experiments are necessary.

1.5 Introduction on biodiesel

Bio-diesel or biodiesel refers to a diesel-equivalent, processed fuel derived from biological sources. Biodiesel is the name for a variety of ester-based oxygenated fuel from renewable biological sources. It can be made from processed organic oils and fats.

Chemically, biodiesel is defined as the monoalkyl esters of long chain fatty acids derived from renewable biolipids. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with the methanol or ethanol in the presence of a catalyst to yield (m)ethyl esters (biodiesel) and glycerin (Demirbas,2002). Fatty acid (m)ethyl esters or biodiesels are produced from natural oils and fats. Generally, methanol is preferred for transesterification, because it is less expensive than ethanol.

The general definition of biodiesel are Biodiesel is a domestics, renewable fuel for diesel engines derived from natural oils like soybean oil, and which meets the specifications of ASTM D 6751. Biodiesel is technically defined by using ASTM D 6751. Biodiesel is a diesel engine fuel comprised of monoalkyl eters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751.

Biodiesel, defined as the monoalkyl esters of fatty acids derived from vegetable oil or animal fat, in application as an extender for combustion in CIEs (diesel), has demonstrated a number of promising characteristics, including reduction of exhaust

emissions. Chemically, biodiesel is referred to as the monoalkyl-esters especially (m)ethyl ester of long-chain-fatty acids derived from renewable lipid sources via transesterification process.

Vegetable oil has too high a viscosity for use in most existing diesel engines as a straight replacement fuel oil. There are a number of ways to reduce vegetable oil's viscosity which are dilution, microemulsification, pyrolysis, and transesterification.

Transesterification (also called alcoholysis) is the reaction of a fat or oil triglyceride with an alcohol to form esters and glycerol. A catalyst is usually used to improve the reaction rate and yield. Because the reaction is reversible, excess alcohol is used to shift the equilibrium to the products side.

The biodiesel reaction requires a catalyst such as sodium hydroxide to split the oil molecules and an alcohol (methanol or ethanol) to combine with the separated esters. The main byproduct is glycerin. The process reduces the viscosity of the end product. Transesterification is widely used to reduce vegetable oil viscosity (Pinto et al., 2005). Biodiesel is a renewable fuel source. It can be produced from oil from plants or from animal fats that are byproduct in meat processing.

One popular process for producing biodiesel from the fats/oils is transesterification of triglyceride by methanol (methanolysis) to make methyl esters of the straight chain fatty acid. The purpose of the transesterification process is to lower the viscosity of the oil. The transesterification reaction proceeds well in the presence of some homogeneous catalyst such as potassium hydroxide (KOH) and sodium hydroxide (NaOH) and sulfuric acid, or heterogeneous catalysts such as metal oxides or carbonates. Sodium hydroxide is very well accepted and widely used because of its low cost and high product yield (Demirbas,2003a).

The mechanism of the acid-catalyzed transesterification of vegetable oils is shown in Figure 1.1, for a monoglyceride. However, it can be extended to di- and triglycerides. The protonation of the carbonyl group of the ester leads to the carbocation II which, after a nucleophilic attack of the alcohol, produces the tetrahedral intermediate III, which eliminates glycerol to form the new ester IV, and to regenerate the catalyst H^+ .

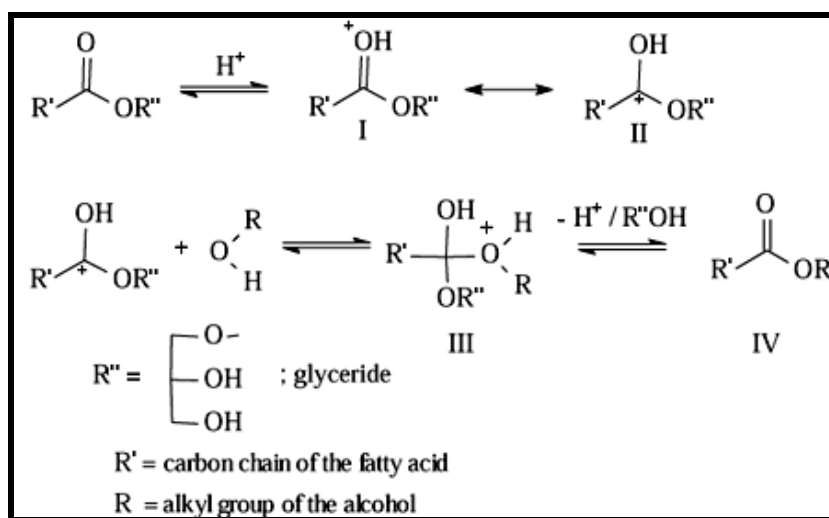


Figure 1.1: Mechanism of acid catalyzed transesterification of vegetable oil.

Removal of this alcohol also removes the water formed by the esterification reaction and allows for a second step of esterification or proceeding directly to alkaline – catalyzed transesterification. Note that the methanol-water mixture will also contain some dissolve oil and FFAs that should be recovered and reprocessed. Figure 1 shows a schematic diagram of the processes involved in biodiesel production from feedstock containing low levels of free fatty acids (FFA) (Gerpen, J.V., 2007).

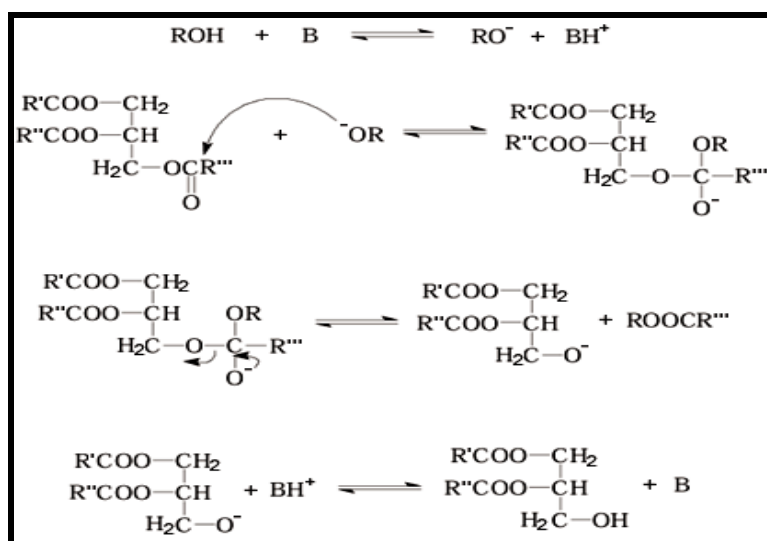


Figure 1.2: Mechanism of base – catalyzed transesterification of vegetable oils

The overall process is a sequence of three consecutive and reversible reactions which di- and monoglycerides are formed as intermediates. Diglycerides and monoglycerides are converted by the same mechanism to a mixture of alkyl esters and glycerol. Transesterification reactions are reversible and typically require excess methanol reactant to help push the equilibrium in the direction of the product biodiesel and glycerol.

Oils and fats are primarily water-insoluble hydrophobic substances of plant and animal origin and are made up of three moles of fatty acids and are commonly referred as triglycerides and one mole of glycerol. Fatty acids vary in carbon chain length and in the number of unsaturated bonds (double bonds). The fatty acids found in vegetable oils are summarized in Table 1.1. Table 1.2 shows typical fatty acid composition of common oil sources.

To obtain crude oil or fats, natural vegetable oils and animal fats were extracted using solvent or mechanical pressed. These usually contain free fatty acid phospholipids, sterols, water, odorants and other impurities. Even refined oils and fats contain small amounts of free fatty acid and water. The free fatty acid and water give significant effects on the transesterification reaction of glycerides using alkaline or acid catalyst.

They also interfere with the separation of fatty acid alkyl esters and glycerol because of soap formation in product.

1.5.1 Composition of Biodiesel

Biodiesel is mixture of fatty acid alkyl esters. If methanol is used as a reactant, it will be mixture of fatty acid methyl ester (FAME). Based on the feedstock, biodiesel has different proportions of fatty acid methyl esters. Most edibles oil and fats contain mainly fatty acids ranging from lauric acid (dodecanoic acid) to arachidic acid (eicosanoic acid). Besides the linear saturated fatty acids, branch fatty acids, mono-unsaturated. Di-unsaturated and higher unsaturated fatty acids can also occur (Frank David column selection for the analysis of FAME). Table 1.3 shows the chemical composition of common fatty acids and their methyl esters present in the biodiesel.

Table 1.1: Chemical properties of vegetable oil on the basis of their fatty acid composition, % by weight (Ma 1999).

Vegetable Oil	16:0	18:0	20:0	22:0	24:0	18:1	22:1	18:2	18:3
Corn	11.67	1.85	0.24	0.00	0.00	25.16	0.00	60.60	0.48
Cottonseed	28.33	0.89	0.00	0.00	0.00	13.27	0.00	57.51	0.00
Cramble	2.07	0.70	2.09	0.80	1.12	18.86	58.51	9.00	6.85
Peanut	11.38	2.39	1.32	2.52	1.23	48.28	0.00	31.95	0.93
Rapeseed	3.49	0.85	0.00	0.00	0.00	64.40	0.00	22.30	8.23
Soybean	11.75	3.15	0.00	0.00	0.00	23.26	0.00	55.53	6.31
Sunflower	6.08	3.26	0.00	0.00	0.00	16.93	0.00	73.73	0.00
Jatropha	14.1	3.7	0.3	0.2	0.00	34.3	0.00	29.0	0.3

Table 1.2: Typical fatty acid composition-common oil source (Ma, 1999)

Fatty acid	Soybean	Cottonseed	Palm	Lard	Tallow	Coconut	Jatropha
Lauric	0.1	0.1	0.1	0.1	0.1	46.5	0.0
Myristic	0.1	0.7	1.0	1.4	0.8	19.2	0.1
Palmitic	0.2	20.1	42.8	23.6	23.3	9.8	14.1

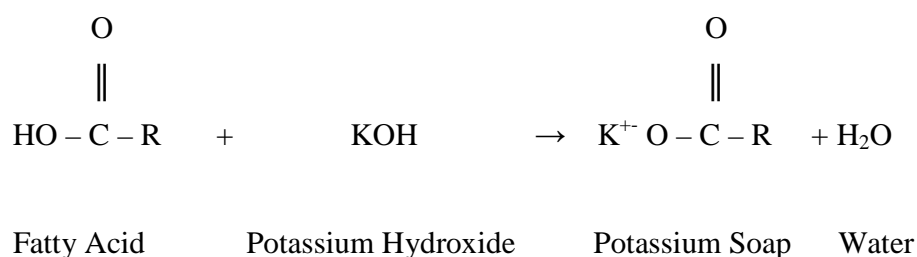
Stearic	3.7	2.6	4.5	14.2	19.4	3.0	3.7
Oleic	22.8	19.2	40.5	44.2	42.4	6.9	34.3
Linoleic	53.7	55.2	10.1	10.7	2.9	2.2	29.0
Linolenic	8.6	0.6	0.2	0.4	0.9	0.0	0.3

Table 1.3: Chemical structures of common fatty acid and their methyl esters.

Fatty acid / Formula	Common acronym	Methyl ester / Formula
Palmitic acid / C ₁₆ H ₃₂ O ₂	C16:0	Methyl palmitate / C ₁₇ H ₃₄ O ₂
Stearic acid / C ₁₈ H ₃₆ O ₂	C18:0	Methyl stearate / C ₁₉ H ₃₈ O ₂
Oleic acid / C ₁₈ H ₃₄ O ₂	C18:1	Methyl Oleate / C ₁₉ H ₃₆ O ₂
Linoleic acid / C ₁₈ H ₃₂ O ₂	C18:2	Methyl linoleate / C ₁₉ H ₃₄ O ₂
Linolenic acid / C ₁₈ H ₃₀ O ₂	C18:3	Methyl linolenate / C ₁₉ H ₃₂ O ₂

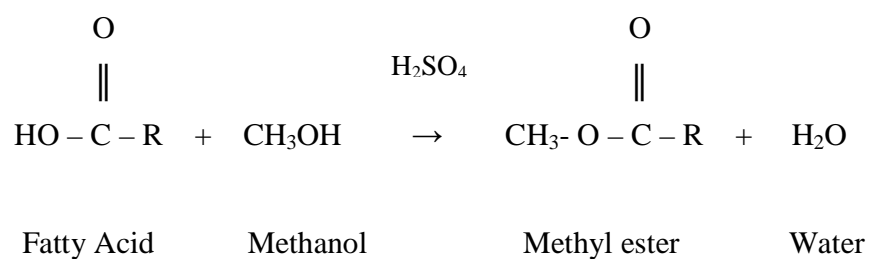
1.5.2 Mechanism of Esterification and Transesterification

Special treatment are required if the oil or fat contains significant amounts of FFAs. Used cooking oils typically contain 2-7% FFAs and animal fats contain from 5-30% FFAs. Some very low quality feedstock, such as trap grease, can approach 100% FFAs. When an alkali catalyst is added to this feedstock, the free fatty acids react with the catalyst to form a soap and water as shown in the reaction below:



Up to 5 % FFAs, the reaction can still be catalyzed with an alkali catalyst but additional catalyst must be added to compensate for that lost to soap. The soap created

during the reaction is either removed with the glycerol or is washed out during the water wash. When the FFA level is above 5%, the soap inhibits separation of the glycerol from the methyl esters and contributes to emulsion formation during the water wash. For these cases, an acid catalyst such as sulfuric acid can be used to esterify the FFAs to methyl ester as shown in the following reaction:



1.6 Objective of Study

To study on difference between lab scale production and pilot plant production of biodiesel production from Jatropha oil.

CHAPTER II

LITERATURE REVIEW

This chapter contains the literature cited in this study. Section 2.1 presents a brief history of scale up study on chemical processes. In section 2.2 is about the process of biodiesel briefly and in section 2.3 is about the Jatropha crude oil.

2.1 Scale up on chemical processes

2.1.1 Scale up

The term ‘scale up’ should not be understood only in the sense of increasing the dimensions while preserving similar systems. Often, the transposition of one system to another offers a better solution to a problem (for example, a pilot plant operating in up flow for an industrial unit operating in down flow). ‘ The development of an industrial process is a creative activity, which is aimed at finding and coordinating all the information and data required for the design, construction and start up of a new industrial unit, in order to guarantee an economically profitable operation’ (Trambouze et al. 1975).

The typical activity of process development work remains the pilot plant experiment. This investigation is necessary for one or more of the following reasons:

- The passage from laboratory apparatus to the industrial installation raises scale-up problems that are too complex to be solved without an experiment performed with components of intermediate size.
- The operating conditions must be investigated in a representative unit, in which the influence of all the parameters, such as the type of feed, impurities, recycle, etc., can be taken into account.
- The study of long-term effects, such as catalyst, the activation, buildup of by-products or impurities, corrosion mechanisms, etc.
- The need to show potential customers an operating pilot plant to convince them of the value of the process and its operational character. This applies especially if the innovative character of the process is a special feature.
- The need to produce representative sample in sufficient quantities for various tests.

This list offers a glance at the essential characteristics of a pilot plant, and especially the requirements that a pilot plant has to meet to perform its role: the pilot plant must simultaneously be transposable or scalable and representative. A pilot plant must therefore be designed to account for these two requirements, while minimizing its complexity and size, which condition the cost of its construction.

However, this work can only be reasonably undertaken if a sufficiently clear idea has first been derived of the future industrial technology. As we pointed out, the success of a scale up depends on this first prospective phase. Based on the information obtained from laboratory experiments and from the literature, one can imagine an industrial unit whose size would correspond to the presumed need of the market. This means working out the details on paper, so as to compare different

technological alternatives, to identify constraints or impossibilities, and finally to select the most interesting industrial flow sheet from the technical economic standpoints.

It is at this level that the type of reactor must be chosen, essentially based on the chemical reactions to be carried out, the phases present, and the industrially feasible technologies. In difficult situations, this choice may not be very clear, so that many possible technologies must be considered. Figure 2.1 shows the essential steps in process development for scale up.

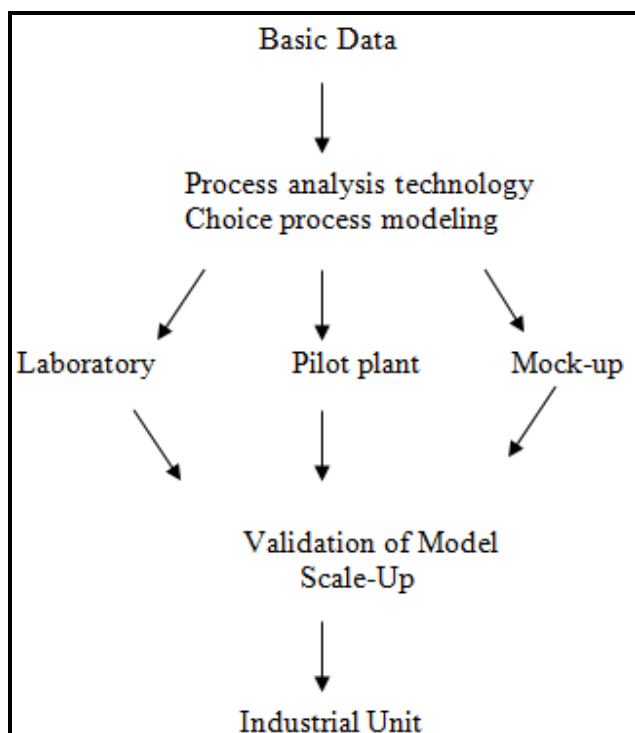


Figure 2.1: Essential steps in process development for scale up

2.1.2 Raw material

The source of the raw material is an important factor. The composition and, especially, the types of impurity and their concentrations depend on the source of

the raw material. It is therefore important for the raw material intended for the pilot plant to be perfectly representative of the material to be used industrially.

In this respect, the use of model molecules, which are useful in conducting kinetic studies or constructing chemical models, is only acceptable if the model molecule is mixed within a representative feed. This makes it possible to investigate the inhibiting or catalytic effect of a given chemical species.

2.1.3 Utilities

Utilities generally include:

- Water (cooling water, de-ionized water)
- Steam at different pressures
- Electricity
- Service air (all-purpose compressed air)
- Instrument air
- Heat transfer fluids
- Inert gases
- Gases, liquid and solid fuels

For a pilot plant, the choice of a given form of utility is based essentially on ease of use, keeping in mind the representatives of the pilot plant.

Thus, for example, electricity is usually used in preference to steam or fuel to heat furnaces, reactors and various vessels. The recovery of the heat or cold is usually ignored, unless it is necessary to examine the problem in itself, in order to determine the transfer coefficients or fouling rates.

2.2 Biodiesel Process

The process for making fuel from biomass feedstock used in the 1800s is basically the same as that used today. Biodiesel from vegetable oils is not a new process. Conversion of vegetable oils or animal fats to the monoalkyl esters or biodiesel is called as transesterification. Transesterification of a vegetable was conducted as early as 1853, by scientists E. Duffy and J. Patrick, many years before the first diesel engine became functional. Life for the diesel engine began in 1893 when the famous German inventor Dr. Rudolf Diesel published a paper entitled 'The theory and construction of a rational heat engine'.

2.2.1 Catalytic Transesterification

The catalyst is dissolved into methanol by vigorous stirring in reactor. The oil transferred into the biodiesel reactor, and then, the catalyst/alcohol mixture is pumped into the oil. The final mixture is stirred vigorously for 2h at 340 K in ambient pressure. A successful transesterification reaction produces two liquid phases; ester and crude glycerin. Crude glycerin, the heavier liquid, will collect at the bottom after several hours of settling. Figure 2.2 shows the schematic of transesterification process.

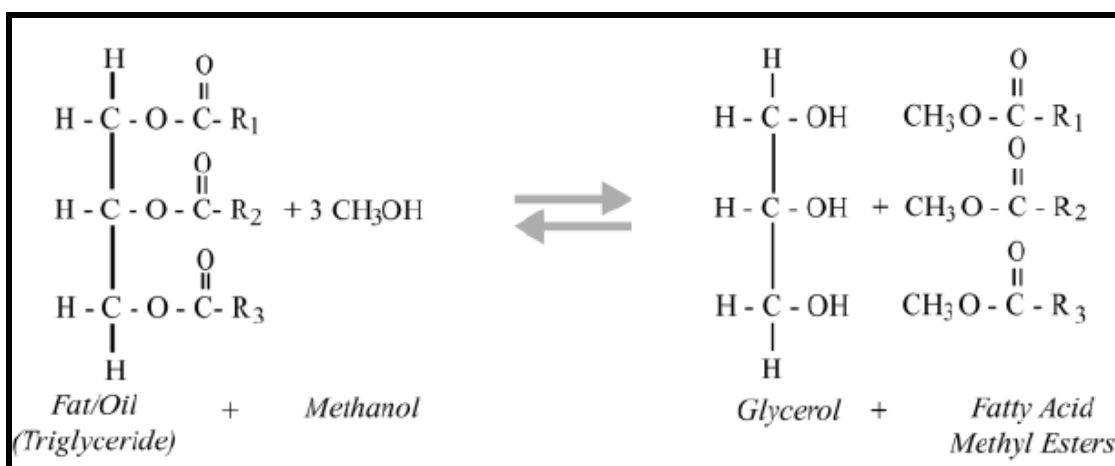


Figure 2.2: Schematic of transesterification process

2.2.2 Background of catalyst in biodiesel production

2.2.2.1 Base catalyst.

Transesterification can be catalyzed by acids, bases or enzymes. Among them, base catalysis is the most popular way and most often used commercially for biodiesel production owing to the high catalytic activity. Also, base catalysts are less corrosive than acidic compounds avoiding the necessity of expensive stainless steel as construction material (Zhang, Y., et al., 2003). Homogeneous base-catalyzed triglyceride transesterification has been thoroughly studied on the laboratory scale. The most common homogeneous basic catalysts used for lipids methanolysis include alkaline metal compounds, such as NaOH and KOH, CH₃ONa and CH₃OK, Na₂CO₃ and K₂CO₃. Alkaline metal alcoxides are the most effective catalysts for the transesterification reaction (Boocock, D. G. B. et al., 1996 and Freedman, B. et al., 1984). As low as 0.5 wt% of catalyst (by the weight of oil) can allow more than 98% biodiesel yielded in very short times. However, in practice, alkaline hydroxides (NaOH and KOH) are more favored because of their cheaper price and easier handling with respect to alkaline alcoxides.

Nevertheless, the use of hydroxides can be problematic considering the formation of water in the initial step of reaction as shows in Fig 1.3 (Schuchardt, U. et al., 1998). Water then hydrolyzes esters to FFAs and consequently causes saponification which in turn translates to catalyst deactivation and productivity loss. Alkaline carbonates can be an alternative choice in order to reduce saponification (Schuchardt, U. et al., 1998) but their use is limited by the weaker base strength.

2.2.2.5 Acid catalysis

Strong liquid mineral acids, such as sulfuric acid, phosphoric acid, hydrochloric acid, and others, are effective for the esterification of FF's with alcohol. They have also been used to catalyze transesterification of TGs to produce biodiesel. However, because of their much lower activity (by 3 orders of magnitude) (Freedman, B. et al. 1986) and much stronger corrosiveness than the base catalysts (Zhang, Y. et al. 2003), the acid catalysts have never enjoyed the same popularity for biodiesel synthesis as its counterpart in both the academic and industrial sectors. Only recently, given the versatility of acid catalysis to deal with FFAs, has its use been proposed as an economically viable alternative to base catalysis for biodiesel formation from low cost feedstock (Zhang, Y. et al. 2003).

2.2.2.3 Esterification of FFAs

As the most common way to synthesize organic esters of enormous practical importance, esterification of carboxylic acids with alcohols, indeed, represents a well-known category of liquid-phase reactions of considerable industrial interest. Simple Brønsted acid catalysts such as H_2SO_4 , HCl , H_3PO_4 and arylsulfonic acid, are generally known to be effective for the direct esterification. Recently, given their non-

corrosiveness and reusability, acidic ionic liquids are proposed as catalysts to offer a new and environmental benign approach for alkyl ester synthesis. Ionic liquids have the potential as dual solvent-catalyst in organic synthesis. And enormous variety of precursors is available to further tune their versatility making them more adapted to a specific reaction.

In most cases, related studies focus on the impacts of reaction parameters on the final free acidity of lipid feedstock without paying much attention to the reaction kinetics. Mainly using H₂SO₄ as catalyst, the pre-esterification of different lipid feedstocks with high FFA contents have been investigated. In accordance, oils with initial FFA contents up to 19% can be easily reduced to 1% or lower using 1-step reaction at 60°C after short reaction time, regardless the origins of oils. The specific efficiency of a process is adjustable by varying operation parameters. For instance, the use of larger amounts of catalysts speeds up esterification rate therefore substantially shortening the necessitated reaction time. Also, higher catalyst concentration appears to favor a deeper FFA conversion before a reaction platform reaches (Ganeshpure, P. A. et al., 2007). However, excessive amounts of acid were observed to darken the ester products by inducing side reactions (Ramadhas, A. S. et al., 2005). Furthermore, the expedient range of H₂SO₄ can be interfered with by either the initial FFA content (Sendzikiene, E. et al., 2004) or methanol-to-oil molar ratio (Veljkovic, V. B. et al., 2006). Typically, catalyst concentration ranged between 1 and 2 wt% (with respect to oil) in academic studies using sulfuric acid.

2.2.2.4 Transesterification of Triglycerides

In contrast to the base-catalyzed biodiesel synthesis, much fewer studies have dealt with the use of acid catalysts in transesterification of lipid feedstock. The slow reaction rate has mainly been why it has fallen into disfavor. Indeed, the homogeneous acid-catalyzed transesterification follows a similar mechanistic route as the acid-

catalyzed esterification, whereby the catalytic turnover is initiated by the activation of carbonyl carbon followed by nucleophilic attack of alcohol to form a tetrahedral intermediate (Loterio, E. et al., 2005, Schuchardt, U. et al., 1998). Disproportionate of this intermediate complex yields the alkyl monoester and diglyceride. This sequence is repeated twice to transform a triglyceride molecule to three alkyl monoesters and one glycerol as ultimate products. Loterio et al. [1] compared this acid-catalyzed mechanism to the base-catalyzed and pointed out that there is a crucial difference lying between them in the reaction initiation steps which mainly discriminate the catalytic efficiency: the formation of a weak and lump electrophilic species (in acid catalysis) vs. that of a strong and small nucleophile (in base catalysis).

2.3 *Jatropha curcas* L. seed oil for biodiesel production.

Jatropha curcas is a drought resistant shrub or tree belonging to the family Euphorbiaceae, as well a family of carrot and tapioca (Sirisomboon, P. et al., 2007).

Classification of *Jatropha curcas* is shown below:

Division	: Spermatopyta
Subdivision	: Angiospermae
Class	: Dicotyledonae
Ordo	: Euphorbiales
Family	: Euphorbiaceae
Genus	: <i>Jatropha</i>
Species	: <i>Jatropha curcas</i> Linn.

Jatropha curcas is well adapted to arid and semi-arid conditions and has low fertility and moisture demand. It can also grow on moderately sodic and saline, degraded and eroded soil (Sirisomboon, P. et al., 2007). The role of *J. curcas* as a substitute for diesel is very remarkable. Table 2.1, shows the major composition fatty acid of *Jatropha curcas* L. seed oil. It is non-edible oil being singled out for large-scale of plantation on